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WATER USE IN LCA

Evaluation of water services system through LCA. A case study for Iasi City, Romania

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Abstract

Purpose The main objective of this paper is to analyse through life cycle assessment (LCA), the entire water services system in Iasi City (Romania): a representative city for the problems faced by the water services sector in Romania. Furthermore, the study is aimed at demonstrating the usefulness of the LCA approach as a support instrument for water resources management.

Methods The life cycle inventory (LCI) of the Iasi water system was organized considering the water system components, as well as their function related to the water use life cycle: before the tap system as production phase (water abstraction, transport, treatment and distribution) and after the tap section as post-use phase (wastewater collection, treatment and discharge). The foreground data describing the LCI processes were provided directly by the company operating the Iasi water system, while the data for the background processes were sourced or selected from Ecoinvent 2.0 database.

The assessment considers the quantification of environmental impacts (according to the CML 2000 baseline and Ecological Scarcity 2006 methodologies) of water supply (abstraction, treatment and distribution) and wastewater disposal (collection and treatment) relative to 1 m^3 of tap water.

Results and discussion For this given system, the results have pointed out that the before the tap system generates higher impacts than the after tap system, mainly due to the energetic effort needed for water supply and the fairly high water losses in the distribution system. However, the after the tap system, specifically the discharge of treated wastewater is still responsible for many of the water-related impact such as Eutrophication (when using CML) or Emissions to surface waters (when using the Ecological Scarcity method). Apart from the LCA approach, this study presents several scenarios for the improvement of the environmental performance of the water services, such as: changing between water sources, improving the distribution system and upgrading the wastewater treatment plant.

Conclusions This study has demonstrated the usefulness of LCA to describe, compare and predict the environmental performance of complex water services systems (and all its components). The results have provided a reference case for the environmental profile of Iasi city water system, and have enabled the identification of its improvement alternatives. Also, this study, which represents a premiere for Romania, has opened future research directions which may include the development perspectives of the Iasi water services system, as well as improvements of LCIA methodologies to better represent the local specific water-related impacts.

Keywords Romania · Water supply · Water systems · Wastewater treatment

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1 Introduction

It is widely accepted that appropriate water supply and sanitation represent some of the key development issues for the

human society for the twenty-first century at global level, numerous organizations and reports presenting alarming figures on water resources availability, the increasing water demands, and water resources pollution, especially in connection to fast population growth and urbanization (WHO 2006; De Albuquerque 2012). Because most of these issues generate social, economical and environmental problems at local and regional levels, their solutions need to be based onto integrated management systems and comprehensive instruments that approach the complexity of water resources in an integrated and coherent framework (Teodosiu 2007). In this context, evaluation and assessment instruments used to identify, describe and quantify all the water-related environmental impacts are urgently needed to support water professionals and decision makers.

Life cycle assessment (LCA) is such an evaluation instrument that allows the identification and quantification of environmental impacts, considering their entire lifespan in a rigorous manner. From this point of view, LCA represents an appropriate support instrument for identifying and assessing the environmental impacts of water services and infrastructure, as well as projecting various scenarios regarding the development of water services. Despite these advantages, there are far fewer studies using LCA in assessing water systems or water as a product, as compared to LCA studies on various other products or services. Nevertheless, LCA has been applied successfully in evaluating the environmental impacts in the water sector (Lundin et al. 2004; Larsen et al. 2007; Lassaux et al. 2007; Hospido et al. 2012), and as a support tool in sustainable water management, providing useful information on the various environmental impacts of existing or projected water-related infrastructure and processes (Hospido et al. 2008, Stokes and Horvath 2010). In most of the cases, LCA has been applied to compare various water treatment technologies (Friedrich et al. 2001; Vince et al. 2008), (advanced) wastewater treatment technologies (Lundin et al. 2000; Rodriguez-Garcia et al. 2011), or sludge treatment technologies (Suh and Rousseaux 2002; Houillon and Jolliet 2005), and, to a lesser extent, to analyse from an LCA perspective the overall water services system (Barjoveanu et al. 2010). For example, Tarantini and Federica (2001) studied Bologna's domestic water supply system with different life cycle impact assessment (LCIA) methods. Lundie et al. (2004) have evaluated Sydney's (Australia) plan for providing water and sewer services in 2021, while Mahgoub et al. (2010) have assessed the current environmental profile and future development scenarios of Alexandria's (Egypt) water system. Lassaux et al. (2007) have studied the impact of using 1 m^3 of water in the Walloon Region (Belgium), providing a comprehensive analysis of the environmental impacts caused by all the water use phases. The results of these studies have presented various environmental profiles, in some cases the water supply contributing to most of the impacts, and in others, the wastewater collection and treatment have presented the highest impacts. It is worth mentioning that comparison among these case studies is very difficult, since all studies were based onto specific systems boundaries and local assumptions, as well as on different impact assessment methodologies.

The main objective of this paper is to analyse from an environmental point of view the whole water services system in Iasi City (Romania) by using LCA in order to identify the main environmental hot spots generated by this system and to provide a solid base for various improvement alternatives. The case study presented in this paper is developed onto Iasi City, which is the third largest city in Romania, and presents the typical operational, economical and environmental problems of most water systems in the country: low connectivity rates to both water and wastewater systems, outdated transport and treatment infrastructure which translate into poor economic and environmental efficiency (Barjoveanu et al. 2011). However, this situation has improved in the last 5 years and has chances to be further developed, considering the funding opportunities (EU's structural funding and national environmental funds) and the development perspectives of the area. This study is intended at assessing the current situation of the water system in Iasi City and presents several scenarios for the improvement of the environmental performance of the water services: switching between water sources, improving the distribution system and upgrading the wastewater treatment plant (WWTP). Furthermore, the study provides a reference case regarding the technical and environmental performance of the Iasi City water services system and demonstrates the usefulness of the LCA approach as a support instrument for water resources management.

2 Materials and methods

2.1 System description and limits

Iasi City is situated in the North-Eastern part of Romania, in the historical Moldova Region and has a population of 350,000 inhabitants (263,410 city proper), according to the 2011 census. Being the most important urban center in the area, it has the most developed water-related infrastructure, for both water supply and wastewater treatment (Fig. 1). The city's water system is managed by a single water company with regional responsibilities (SC APAVITAL SA IASI), which supplies water supply services, as well as wastewater management services in Iasi City. The main characteristics of the water and wastewater systems in Iasi city are presented in Table 1.

2.1.1 Water supply system

Iasi city has a complex water supply system that comprises both groundwater and surface sources (Fig. 1):

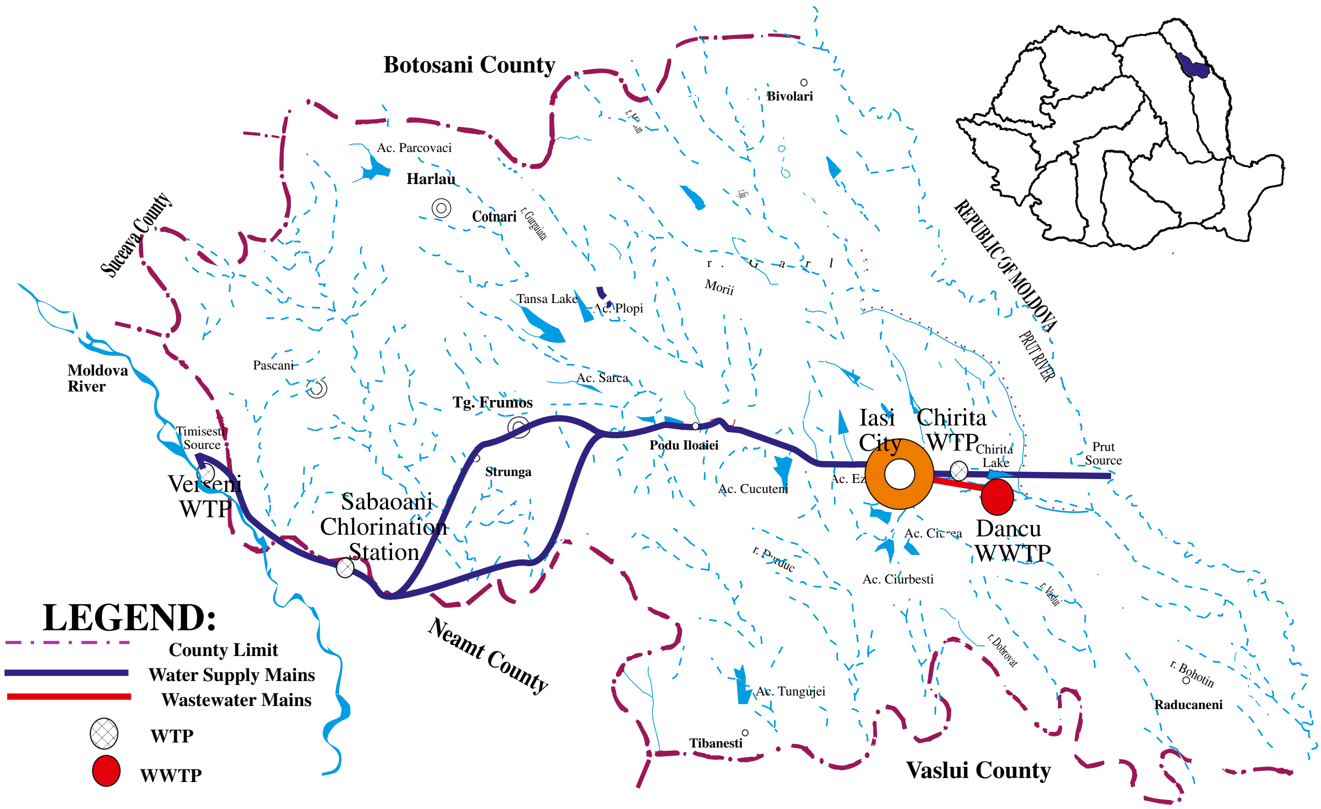

Fig. 1 Iasi county and water supply system

(a) The Timisesti water supply system is located approximately 100 km west of the city and comprises two drain fields, two well fields and a backup surface source on Moldova river. This system is the oldest water source of Iasi city (first commissioned in 1911) and upgraded in 1975 and later in 1990. The two drain fields provide high quality water that only requires disinfection (realized at Sabaoani Chlorination Station, some 60 km west of Iasi city) and provide most of the water supply for this system. Despite the long distance, this system is efficient from an energetic point of view, pumping is necessary only for water abstraction from the two well fields (used mainly as protection for the main drain fields) and for the surface source. The surface water source of this system is located on Moldova River, which provides water through a treatment station, Verseni Water Treatment Plant (WTP), and feeds the same main collectors. This water supply system provides water for Iasi city as well as for seven towns along its route: Halaucesti Strunga, Targu Frumos, Baltati, Podu Iloaiei, Letcani and Valea Lupului.

(b) The Prut water supply system uses water from the Prut River (a trans-national river) and is located some 20 km east of the city, supplying the city through the Chirita Water Treatment Plant either directly through two mains, or through the Chirita Lake, which acts as a pre-sedimentation buffer in case of high turbidity water.

Table 1 Water and wastewater services in Iasi City in 2010

Indicator	Unit	Iasi City
Population (metropolitan area)	No.	349,992
Population (city)	No.	263,410
Water supply customers	No.	261,384
Water supply connection rate (metropolitan area)	%	82.93
Supplied water volume (including industrial water)	m^3	61,615,721
Billed water volume (water consumption)	m^3	36,351,458
Total water losses in distribution system (supplied water−billed water)	m^3	25,264,263
Total water losses in distribution system (loss volume/supplied volume)	%	41.00
Connection rate to sewage system	%	80.69

The characteristics of the water treatment facilities are presented in Table 2. As indicated above, the Verseni WTP treats surface water from Moldova River, which is disinfected at the Sabaoani Chlorination Station together with the groundwater, while the Chirita WTP treats the water coming from the Prut source.

Table 2 Water treatment infrastructure of Iasi water supply system

Treatment plant	Timisesti system		Prut system
	Verseni treatment plant	Sabaoani chlorination station	Chirita treatment plant
Function	Mainly backup for groundwater sources	Disinfection for all Timisesti water supply system	Complete treatment for the Prut water supply system
Max. capacity (m^3/day)	51,840	129,600	98,400
Supplied water volume (2010) (m^3/year)	9,220,000	36,454,700 (including Verseni WTP)	25,161,021
Water supply ratio for Iasi city (2010)	–	60.14 % (including Verseni WTP)	39.86 %
Technology	Coagulation/flocculation–sedimentation–filtration	Disinfection with liquid chlorine	Pre-chlorination (ClO_2), coagulation/flocculation ($FeCl_3$), sedimentation, ph adjustment, sand filtration, GAC filters, disinfection (Cl_2)

2.1.2 Water distribution system and wastewater collection

The distribution system in Iasi city comprises seven storage/pumping stations, divided between the two main sources and uses a 733.5-km network (including transmission mains). While the pumping stations and storage facilities are generally in good condition, the average specific energy consumption of Iasi city's water supply peaks during the high-demand hours at 0.35 kWh/m^3 due to the hilly terrain.

The distribution system of Iasi city provides water to households (36.96 %), municipal users (30.44 %) and industrial facilities (32.60 %), which are supplied via a dedicated distribution system connected to the Chirita WTP.

Wastewater is collected through a 428-km unitary sewage system that transports gravitationally an average of 210,000 m^3/day mixed wastewater (domestic, industrial and storm water) to the Dancu WWTP. The sewage system is equipped with 7 emergency wastewater-pumping stations in case of heavy precipitation. The sewage network is also in a rather poor state, needing constant maintenance and repair interventions (approximately five interventions per kilometer per year).

2.1.3 Wastewater treatment

All wastewater collected from Iasi city is treated at the Dancu WWTP (both mechanically and biologically) and then is discharged into the Bahlui River. Dancu WWTP has recently undergone major upgrading, its capacity being increased from 190,000 m^3/day and 37,300 kg BOD/day to a maximum flow of 280,000 m^3/day and 56,000 kg BOD/day. At the time of this study, the new treatment line was in testing phase, and the system considered in this paper considers the old treatment facility that could not perform complete mechanical and biological treatment for all the influent wastewater. Because of this in 2010 approximately 30 % of the plant's effluent was discharged in the Bahlui River after mechanical treatment only. Sludge management was done mainly through dewatering and landfilling, while the upgrade project includes a complete biogas production facility using biological sludge.

2.2 Functional unit

This study is intended to assess the environmental profile of the water system for Iasi city. For this, we have considered 1 m^3 of tap water delivered in Iasi City in 2010 for all types of uses (domestic, public and industrial) as the functional unit. The system limits include all the water processing phases as presented in Fig. 2, along with the respective measured water volumes, relative to the functional unit. So, it can be seen that for delivering 1 m^3 of tap water in Iasi City, 1.695 m^3 of water have to be abstracted, treated and distributed.

Furthermore, because Iasi city has a unitary wastewater collection system, the Dancu WWTP treats a volume of 2.087 m^3 of wastewater per 1 m^3 of tap water. Additionally, approximately 20 % of the generated wastewater does not reach the collection system, which is considered as untreated wastewater. Because there are some water flows whose proportion is difficult to be quantified in the wastewater mix and for which no data was available (i.e. bottled water and beverages consumption, and other evaporative water uses like cooking and irrigation), we have adopted a conservative approach regarding the wastewater origin and have considered that the whole water arriving at the tap becomes domestic wastewater and follows the traces also presented in Fig. 2.

2.3 Life cycle inventory and data collection

The life cycle inventory (LCI) of the Iasi water system was organized considering the water system components, as well as their function related to the water use life cycle (i.e. before the tap system=production phase and after the tap section=post-use phase). Furthermore, the LCI was organized in a detailed manner, considering the available data, as well as

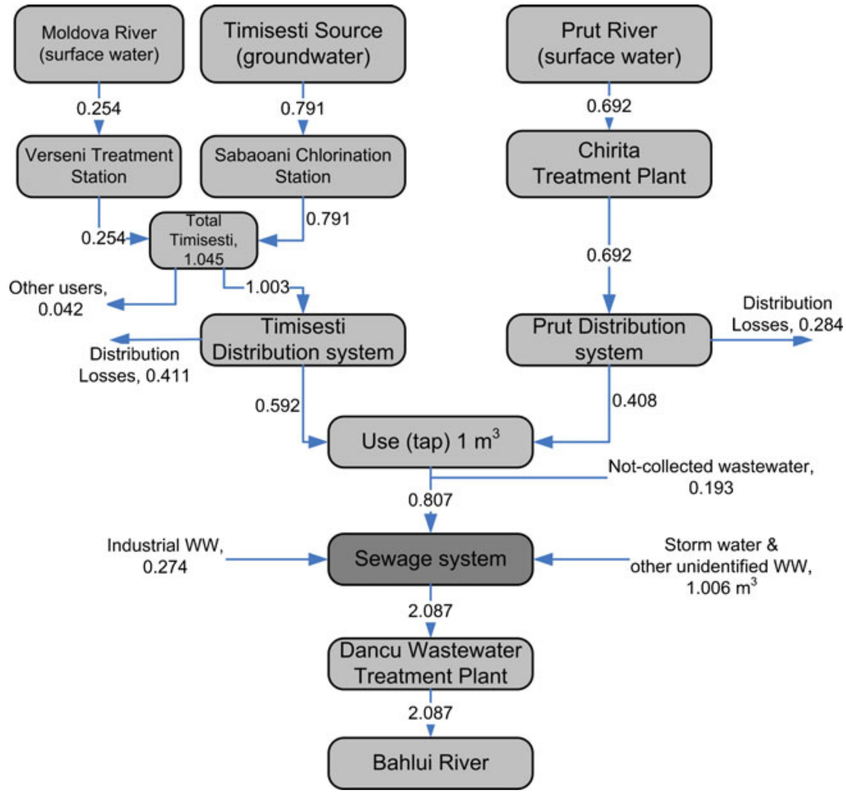

Fig. 2 Water balance for Iasi city, relative to 1 m^3 of tap water

the system characteristics and individual components, as presented in Table 3.

Previous studies have pointed out that the construction and end-of-life stages have a limited contribution to the total impacts of water services compared to the operational phase (Friedrich et al. 2001; Vince et al. 2008). Since this study approaches the operational phase of Iasi water system, the LCI only includes the piping materials required for water distribution and wastewater collection, but not the works associated with the construction or decommissioning processes of the whole system. However, because we refer to the operational phase of the water system, we have included maintenance processes for the water distribution network and wastewater collection network. These processes consider material use (piping materials), repair works (expressed as diesel consumption), as well as wastes generated in maintenance operations of these networks.

The foreground data describing the LCI processes were provided directly by the company operating the Iasi water system or it was sourced from activity reports and other related documents (i.e. water management permit and environmental permit documentation).

The system under study includes different background processes associated with the production and transport of chemicals and energy used for the whole system, which was selected from Ecoinvent v 2.0 database (Swiss Centre for Life-cycle Inventories 2008). A detailed LCI description for all system components and considered Ecoinvent processes and materials is provided in the Electronic Supplementary Material.

2.4 Life cycle impact assessment methodologies

The life-cycle modeling and impact assessment was conducted by using SimaPro 7.3.3. (Pre Consultants 2008). CML 2000 baseline (Guinée et al. 2001) was selected for life cycle impact assessment because it is one of the most used impact assessment methods in water-related LCA studies (Hospido et al. 2008; Renou et al. 2008; Godin et al. 2011) and this enables comparison if other elements are coincident (i.e. functional unit, system boundaries, etc.).

The CML 2000 baseline methodology considers the following impact categories: abiotic depletion (AD), acidification (AC), eutrophication (EU), global warming potential (GWP), ozone layer depletion potential (ODP), human toxicity (HT), terrestrial eco-toxicity (TE), marine aquatic eco-toxicity (MET), freshwater aquatic eco-toxicity (FET) and photochemical oxidation potential (PO).

Because the CML 2000 baseline is a mid-point impact assessment method, the Ecological Scarcity 2006, which is an end-point, damage-oriented method was also used as a valuation method to distinguish between the most important impact categories, from the following: emission into air, emission into surface water, emission into ground water, emission into top soil, energy resources, natural resources and deposited waste.

Life cycle impact assessment has been performed at impact characterization and normalization levels for CML 2000 baseline and to the single-score level for the Ecological Scarcity 2006 method. The normalization factors were updated with

Table 3 Inventory elements, Iasi water services

Water use cycle stage	LCI process/material	Data type/source	Assumptions/estimations
Water abstraction	Abstraction water volumes	Measured	–
	Infrastructure	Measured	Includes only materials for transmission mains
	Energy	Estimated	Based on water volumes and rated pumping power
Water treatment	Treated water volumes	Measured	–
	Chemicals	Measured	–
	Chemicals transport	Estimated	Known distances, estimated transport type
	Energy	Measured	Includes energy for WTP operations
	Operation/maintenance	Measured	Includes energy consumption for support WTPs processes (heating mainly)
Water distribution	Distributed and billed water volumes	Measured	–
	Energy	Measured/ estimated	Measured total energy use, estimated distribution among system components
	Infrastructure	Measured	Includes piping materials
	Maintenance	Measured	Includes fuels used for system repair and maintenance
Wastewater collection	Collected wastewater volumes	Measured	–
	Energy	Measured	–
	Infrastructure	Measured	Includes piping materials
	Maintenance		Includes fuels used for system repair and maintenance
Wastewater treatment	Wastewater volumes	Measured	–
	Chemicals	Measured	–
	Chemicals transport	Estimated	Known distances, estimated transport type
	Energy	Measured	–
	Sludge management	Measured	Known heavy metal releases, estimated N and P emissions to air and water
	Final effluents chemical composition	Measured	For phosphorous, only a limited amount of samples were available

the EU 25+3, 2000 data set provided by CML (http://cml.leiden.edu/software/data-cmlia.html).

3 Results

3.1 Environmental profile of the whole water system

The results presented in Fig. 3a show that in the impact characterization step of LCIA using the CML 2000 baseline methodology, between 70 and 78 % of the total impact in all categories is produced in the before the tap phases of the water use cycle, except for Eutrophication where the after tap section of the water cycle generates most of the impact. These results are confirmed also in the normalization step of LCIA (Fig. 3b), which allows for a comparison among impact categories and which shows that the highest impacts are produced in the following impact categories: marine aquatic ecotoxicity (MET), fresh water ecotoxicity (FET), eutrophication (EU), terrestrial ecotoxicity (TE) and abiotic depletion (AD). The high impacts in the MET category are given by heavy metals (such as Berylium or Vanadium, among others) which appear in various background processes related to energy production. These emissions present high uncertainties and thus it is necessary to consider the results regarding this impact category cautiously.

The highest impacts are generated by the water distribution system, mostly because of its poor efficiency rather than its pollution emissions, followed by the water treatment systems. Wastewater collection and treatment generate higher impacts only in the eutrophication category, mainly due to the remaining nutrients in the treated wastewater, as well as the sludge landfilling.

When using the Ecological Scarcity 2006 method, the environmental profile of Iasi city water system (Fig. 4a) shows that the most important impact categories are: the emissions to surface water (1,933 Pt), followed by the emissions to air (1,089 Pt), and the natural resources (238 Pt). It is important to note that in the emissions to surface water, the highest contribution is given by the wastewater treatment, which of course is connected to the direct discharge of effluents in the natural environment. The second-most relevant impact category according to this single-score method is the emissions to air category. Here, the before the tap sections (and especially the

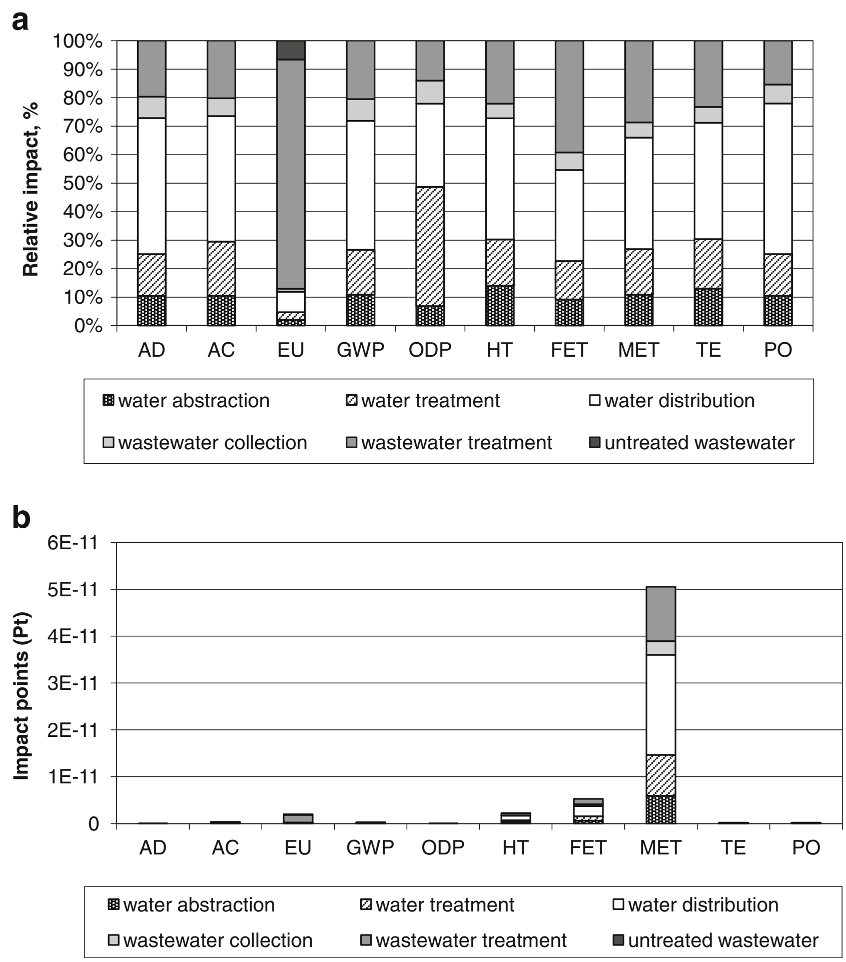

Fig. 3 Environmental profile of the water system in Iasi city using CML 2000 baseline (**a** characterization and **b** normalization)

water distribution) generate the highest impacts and these impacts are mainly related to energy generation.

The comparison between the water production (abstraction, treatment, distribution) and wastewater management (wastewater collection, wastewater treatment and untreated wastewater) shows that the latter sub-system generated higher impacts than the water supply and distribution subsystem (2246 and 1286 Pt respectively). This profile is contrary to the one generated through CML 2000 baseline method and the most important explanations to this is that the Ecological Scarcity is a damage-oriented LCIA method and it does not have characterization factors for all the impact generators in the LCI. Moreover, the Ecological Scarcity method uses normalization factors for impacts like euthrophication considering the situation in Western-Europe, where this impact is an important problem. In the next sections, the impact profiles of each water subsystems are separately presented and discussed in detail.

3.2 Water supply system analysis (before the tap phases)

The water supply system of Iasi city is analysed considering its two major subsystems:

- The Timisesti system, comprising the groundwater and surface water sources on Moldova River, which subsequently undergoes chlorination at Sabaoani station and is distributed mainly in the hilly part of the city with the help of three booster stations;
- The Prut system, supplying the city with surface water from the Prut River, which is treated at the Chirita treatment plant and then distributed throughout the city by two pumping stations.

In Fig. 5a, a comparison between the normalized impacts associated with the different water supply system components is presented. The most relevant impact categories are the Marine aquatic ecotoxicity and the Freshwater aquatic ecotoxicity, while the highest impacts in all categories are due to the Prut system, with Chirita WTP giving the highest scores, followed by the abstraction from the Prut River and the distribution system. The impacts of the Timisesti water supply system are small, only the distribution system that is fed with Timisesti water gives comparative impacts to the Prut distribution system. It is important to note that the impact scores obtained in the MET and FET impact categories are mostly related to energy production processes. This is confirmed by

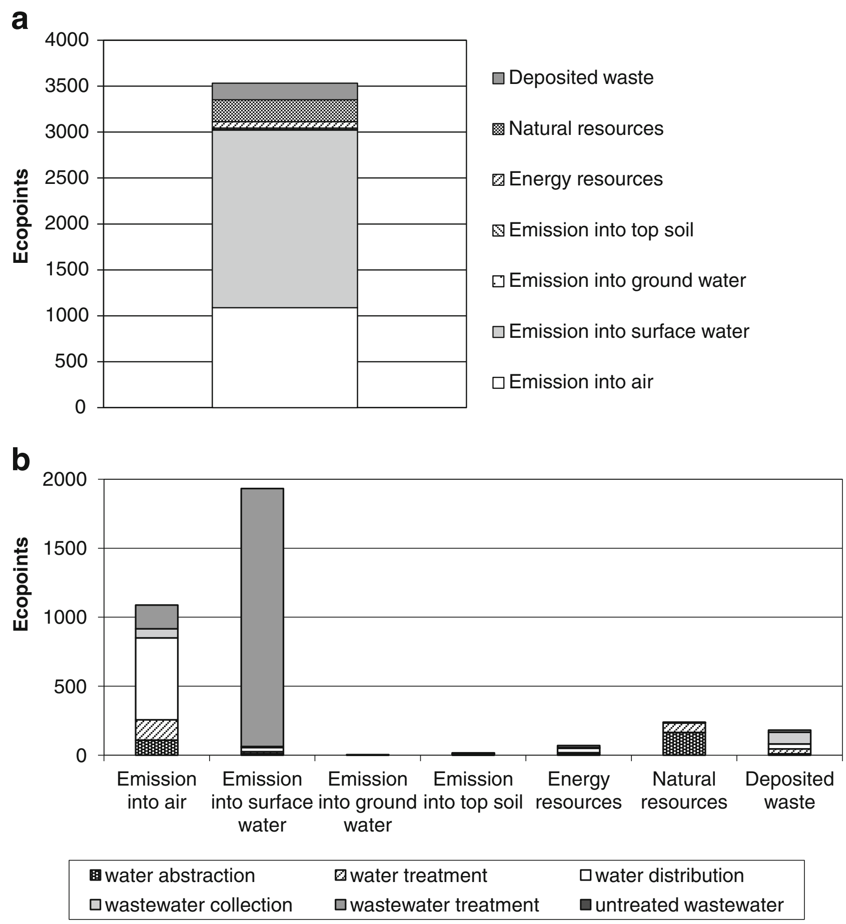

Fig. 4 Single score environmental profile by using the Ecological Scarcity 2006 method (**a**). impact categories contribution to total, **b**) water system components contribution to various impact categories)

the single-scores obtained with the Ecological Scarcity 2006 method and presented in Fig. 5b, where one may notice that the Emissions to air (associated with energy production) is the most relevant impact category, followed by the Natural resources impact category (associated to water abstraction).

As presented in Fig. 5, the distribution system of Iasi City, comprising the two sub-systems (Prut and Timisesti) generates similar impacts in all categories. This happens because the Timisesti system uses gravity for water transport from the source to the city gates (only 3.35 % of the total energy is used for water transport in this system), while all the production steps of the Prut system are based on active pumping.

3.3 Wastewater collection and treatment (after the tap phases)

The after the tap stages in the water service system in Iasi city generate only approximately 20–25 % of the total impacts (see Fig. 3), these impacts being detailed in detail in Fig. 6. The wastewater treatment plant generates the highest impacts, followed by the sewage system and the untreated wastewater, which only generates impacts in the Eutrophication category. For the untreated wastewater system, the singular impacts in the Eutrophication category are explained by the limited information available for the untreated wastewater where only eutrophication-related parameters were measured (COD and N). An effect in the toxicity-related impacts would be expected had heavy metals (or micropollutants) been measured. However, considering the contribution of this stage to the impact in EU category, we can assume also a minor contribution to other impact categories.

4 Discussion and scenario analysis

The impact profile of the Iasi water supply system is a direct consequence of its configuration, the age of the system and its energy requirements. This represents a reference situation for which some improvement alternatives can be suggested. One important observation is that the chosen impact assessment methodologies do not characterize all the water-related impacts (Berger and Finkbeiner 2010). Instead, this research focuses on how the water system has an environmental impact on non water-related aspects and how changes in the system can affect its environmental profile.

Having two very different water sources (ground and surface water, as presented in Fig. 5), the fraction that is taken

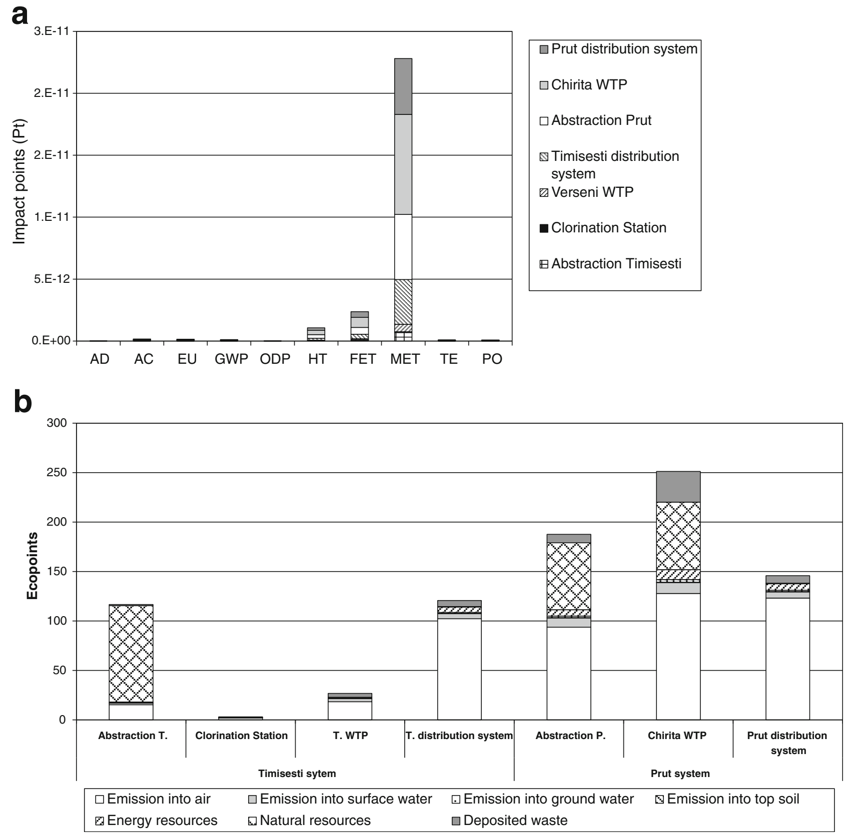

Fig. 5 Environmental profiles of the water supply system components (**a** normalized CML 2000 baseline and **b** single score Ecological Scarcity)

from each one can significantly affect the environmental profile of the whole water system. Aside from this, two of the main characteristics of Iasi water system are the high water losses before the tap and the low connection rate to the sewerage system (see Table 1 and Fig. 2). Finally, according to Figs. 3 and 6, the fraction of collected wastewater that is not treated, 12 %, results in a significant impact on the eutrophication impact category. Considering these aspects, a series of five improvement scenarios, presented in Table 4 are analysed in the next sections.

4.1 Water supply system

4.1.1 Water sources

As previously discussed some of the highest impacts generated by the water services in Iasi City are given by the water supply system. These are mainly caused by the energy use for water abstraction, water treatment, and most importantly, the water distribution system. As presented in Fig. 5, the Prut water supply system supplying treated surface water generates considerably higher impacts than the Timisesti supply system (surface and groundwater sources). In Fig. 7, two scenarios regarding some modifications in proportions of the supply of water in the Iasi are presented against the current situation (2010), where the groundwater source represents 60 % of the total distributed water, while the surface water accounts for 40 %. If the amount of Timisesti water is raised to 80 % of the total (scenario S1.1), this would lead to a 5–20 % decrease of the CML 2000 environmental impacts (Fig. 7a) and to 9.26 % decrease in the Emissions to air category and 14.70 in the Natural resources category (Fig. 7b, Ecological Scarcity), respectively. By contrast, the increase of the surface water proportion to 80 % (scenario S1.2.) would produce significantly higher CML 2000 impacts, which relate mainly to higher air emissions generated by a higher energy requirement, according to the single scores presented in Fig. 7b. It is also important to note that the scenarios presented in Fig. 7 represent the changes in the whole water services system (2010) given solely by the water supply system.

This analysis shows that the groundwater source is very valuable for Iasi City, due to its high quality and limited treatment necessity, as well from an energetic point of view thanks to its gravitational delivery system. Moreover, this analysis indicates that relying more on the groundwater source could lead to environmental improvements. However, such an optimization should also consider the environmental effects of the groundwater abstraction, and the availability of the water resources, which are not described by the CML method and considered by the Ecological Scarcity method at a too wide

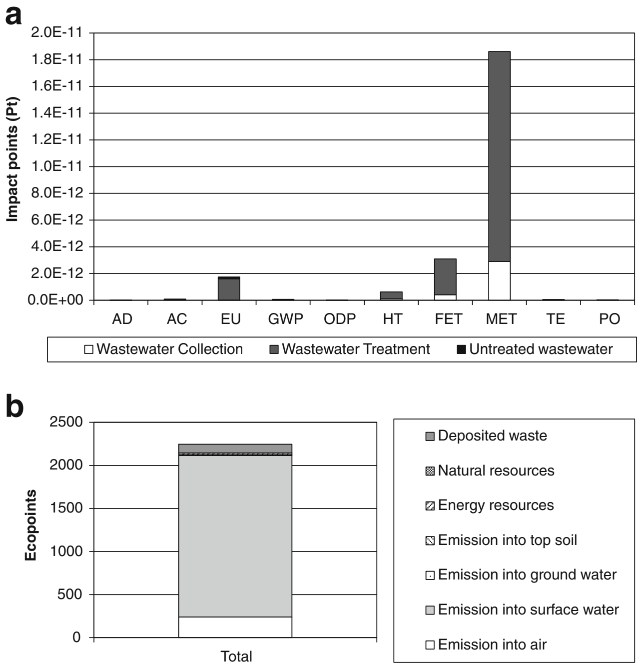

Fig. 6 After the tap contributors to the wastewater system environmental profile (**a** normalized CML 2000 baseline and **b** single score Ecological Scarcity 2006)

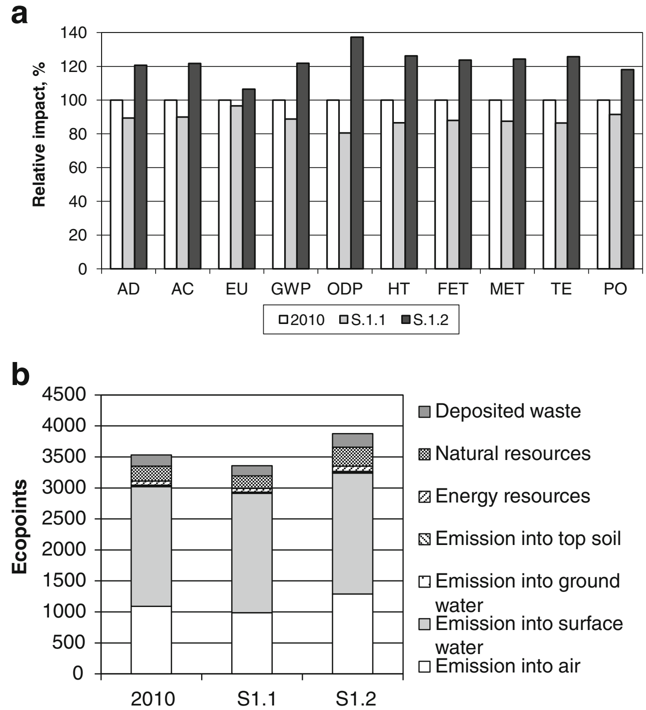

Fig. 7 Scenarios regarding the water sources (**a** CML 2000 normalization results and **b** Ecological Scarcity single score)

scale (i.e. the characterization factor for water scarcity is an average for Europe). Such an investigation is planned for the future and it will consider the local quantitative and qualitative conditions of the two water sources, as well as the adaptations to the local conditions of the LCIA methods.

4.1.2 Distribution system

The water distribution system of Iasi City generate the highest impacts among all the water system's components, in general due to the high-energy input needed to pump water in the distribution system (77 % of the total impact) and due to the maintenance operations (23 %). But the most important issue related to the distribution system is represented by the high water losses, which account for 41 % of the total produced water. This situation is caused by the old age of the system; in some areas of the city the distribution network is over 100 years old and has a real loss factor of over 75 %. The water operator in Iasi city has conducted an internal survey showing that is feasible to decrease the real water losses to 28–29 % by refurbishing about 15 % of the distribution network (ILF Consulting Engineers and Ingineure 2009). In Fig. 8, a comparison between the current situation (2010) and the scenario according to which water distribution losses decrease to 28.7 % is presented. The scenario does not account for works needed to implement the network changes, but considers a 50 % decrease of the maintenance effort (computed as 50 % drop in the diesel consumption). It may be noticed that this would lead to impact decreases of 2.04 % (EU) to 16.32 % (ODP) when using the CML 2000 impact method. The most important changes according to the Ecological Scarcity method are related to the

Table 4 Improvement scenarios related to the Iasi water services system

Number	Scenario area	Description	Changes from reference (2010)
S1.1./S1.2	Water supply system	Changes in the water supply profile.	S.1.1. 80 % Timisesti ; 20 % Prut system S.1.2. 20%Timisesti, 80 % Prut system
S2	Water distribution system	Decrease of water distribution losses.	Real water losses within the system decrease to 28.7 %
S3	Wastewater collection system	Improvement of connection rate to sewage system	100 % connection to sewage network (0 untreated wastewater)
S4	Wastewater treatment	WWTP performance improvement.	100 % of the wastewater flow is treated both mechanically and biologically

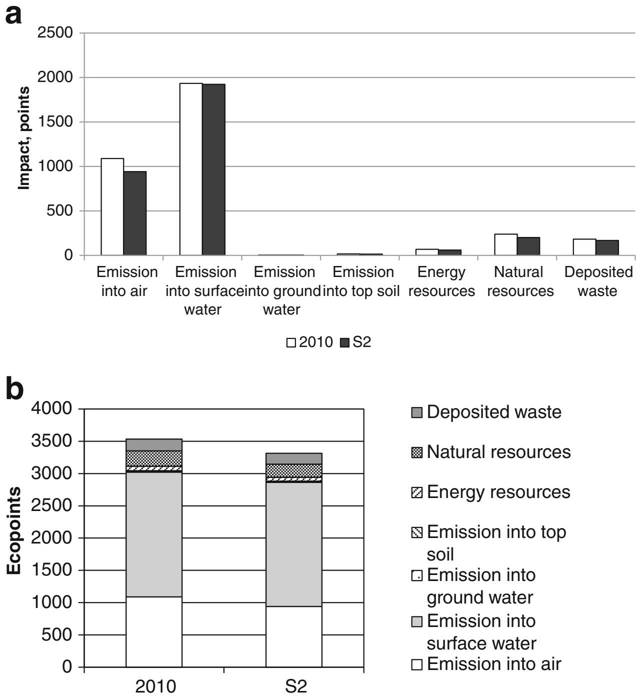

Fig. 8 Environmental profile given by changes in the distribution system (**a** normalized CML 2000 baseline results; and **b** Ecological Scarcity single-score results)

production and use of energy in the distribution system: −13.53 % in air emissions, −14.38 % in energy resources. Also, by decreasing the water losses in the distribution system may lead to significantly lower impacts in the natural resources category (−15.40 %). In the emission into surface water category the changes are minor (−0.53 %), which shows that the distribution system has a very limited contribution to this impact category.

4.2 Wastewater collection and treatment

The after the tap section of the water use cycle in Iasi city is responsible for approximately 25–30 % of the total water cycle impacts, except the eutrophication category, where it is responsible for 80 % of the impact as it was presented in Fig. 3. The impacts of the wastewater collection system are due to the energy used for pumping wastewater (77 %), as well as by the maintenance operations (23 %) especially for de-clogging of the sewage systems. These numbers are based only on the operational phase in the wastewater collection system life cycle, as construction and rehabilitation works are not considered in this study. Roux et al. (2011) have shown that these processes may contribute to a great increase of the wastewater collection system contribution to the overall after the tap system impacts, in different categories, except for eutrophication where the WWTP generate higher impacts.

The environmental profile of the WWTP presented in Fig. 9 shows that the biological wastewater treatment stage generates the highest impacts, followed by the mechanical treatment and the sludge treatment. According to the mid-point perspective (see Fig. 9a), the most relevant impact categories are associated to the energy and material use (MET and FET), and to the discharge of nutrients (EU). This is due to the fact that the largest impacts in most categories are related to the use of electricity, as about 84 % of the total WWTP energy consumption goes in the aeration of the activated sludge tanks. An exception is the EU impact category where most of the impact is associated with water discharges in the mechanical and biological stages (especially nutrients) and, to a lesser degree, to phosphorous leakages in the sludge disposal stage. A different situation is presented by the end-point perspective (Ecological Scarcity method depicted in Fig. 9b) where the emissions into surface water is the most important impact category, followed by the air emissions (due to energy use). This difference is given by the different approach in calculating impacts by the two methods.

The improvement opportunities for the wastewater supply system consider a higher connectivity rate to the sewage system (100 %, Scenario 3, Fig. 10) and the treatment of all wastewater through both mechanical and biological stages (scenario 4, Fig. 10). The scenario presented in Fig. 10a shows that according to the CML 2000 method, the improvements given by scenarios 3 and 4 are in the Eutrophication category (4.44 and 12.66 % respectively), but on the other hand, this is possible at the cost of higher impacts in the other impact

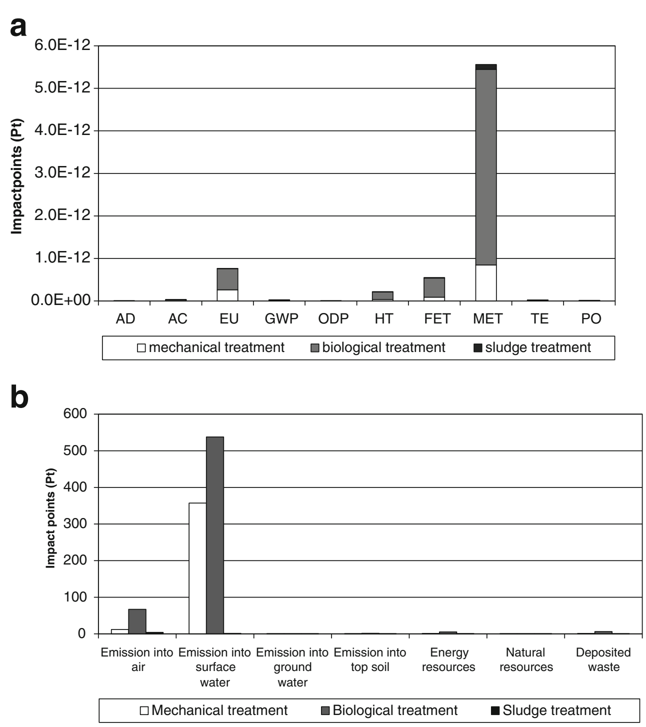

Fig. 9 Environmental profile of the Dancu WWTP in 2010 (**a** normalized scores using CML 2000 and **b** single score using Ecological Scarcity)

categories, due to the additional effort needed to process the extra volume of wastewater. In Fig. 10b, a comparison between the S3 and S4 scenarios by using the Ecological Scarcity method is presented. It shows that by connecting all wastewater to the WWTP (S3) leads to increased impacts for emissions to surface waters (+8.97 %) due to a larger wastewater volume to be treated, while the largest positive effect appears in the emissions to groundwater (− 86 %). If all wastewater is treated both mechanically and biologically (S4 in Fig. 10b), a significant improvement is obtained in emissions to surface water (21.38 % decrease). Furthermore, data in Fig. 10b shows that the impact increases in the other categories are minor (0.15 to 6.10 %), which suggests that this improvement scenario is feasible. On the other hand, this analysis shows that if improvements are made in the wastewater collection system, these have to be backed-up by improvements in the wastewater facilities as well.

As presented before, for the water system in Iasi city, several options are readily available for addressing specific efficiency issues. Data presented in Fig. 11 depict a comparison among the studied scenarios in this paper and suggest that from the environmental point of view, addressing the issues of the water supply system would produce more benefices in the energy production and use and the natural resources impact categories (Fig. 11b). Thus, decreases of 12.26 % in the emissions to air, 10.71 % in energy resources and 14.69 % in natural resources, respectively, were recorded, while upgrading the wastewater system would lead to a 23.7 % decrease of the eutrophication

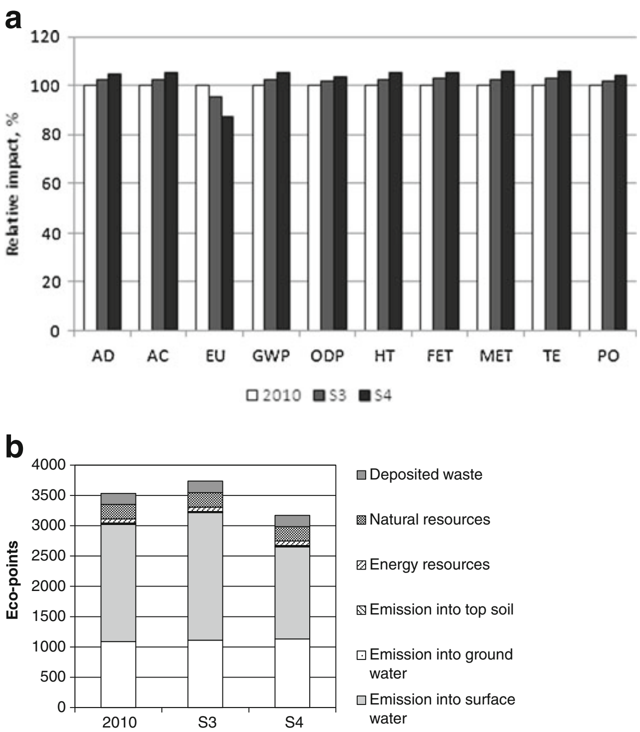

Fig. 10 Comparison of current situation and scenarios 3 and 4 (**a** CML 2000 normalized results and **b** Ecological Scarcity single score)

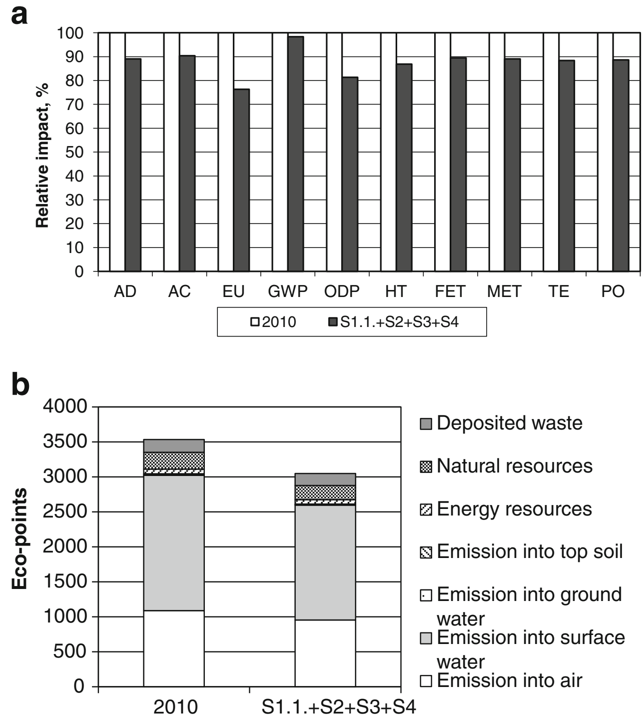

Fig. 11 Comparison of the baseline situation and the implementation of all improvement scenarios (S1.1+S2+S3+S4), (**a** CML 2000 characterization and **b** Ecological Scarcity 2006 single score)

impact (Fig. 11a) or a 15.10 decrease of emissions to surface waters (Fig. 11b). Furthermore, for the water supply system the improvements in the water distribution would lead to higher benefices (especially in the energy and resources-related impact categories), while for the wastewater sector apart from the suggested scenarios, an improved nutrient removal at the WWTP should be implemented. This analysis does not take into account the development perspectives of Iasi City, and from this point of view, this study is just a starting point to study the environmental impacts of the development of Iasi city.

5 Conclusions

The main objective of this study was to use LCA to analyse the environmental profile of the water system for Iasi City (Romania) from the abstraction of raw water to the discharge of the wastewater treatment plant final effluent, so as to identify the environmental hot spots and to study some improvement alternatives for both the before and after the tap systems. These environmental profiles were generated by using two methods: CML 2000 baseline was used for the characterization and normalization steps of LCIA and the Ecological Scarcity 2006 was used as a single-score method.

The water pollution impacts (eutrophication in CML 2000 and emissions to surface waters in Ecological Scarcity 2006)

have been confirmed as relevant through the whole water cycle, as indicated by previous studies such as Lassaux et al. (2007) and Mahgoub et al. (2010). These impacts are mainly associated with the effluents from the WWTP in Iasi City. The same impact is emphasized by the wastewater fraction that only goes through mechanical stage, suggesting that a larger, more efficient WWTP is required, as presented in the dedicated scenario analysis. For the other impact types, the largest impacts are caused by the water supply system, which contribute to approximately 75–80 % of the total impact in all impact categories with the exception of eutrophication. These impacts are mainly caused by the high-energy use for water abstraction, water treatment, and most importantly the water distribution system. The surface water component (the Prut water supply system) generates considerably higher impacts than the groundwater sub-system (Timisesti source), although the latter source is some 100 km away from the city. In general, the results presented in this study do not differ very much from the other (few) reports that have studied the whole water use cycle through LCA , especially regarding the high impacts caused by the water supply system and the impact structure of the WWTP. Considering the current operational and efficiency problems of the Iasi water system, a set of alternative scenarios were considered, in order to study the most important improvement directions for the whole system. The results have pointed out that by improving the water supply system would lead to decreasing in the energy and natural resources-related impact categories, whilst improving the wastewater management would reduce the impacts in the water pollution-related categories.

The analysis in this study is based onto existing and well-established LCIA methodologies, the CML 2000 Baseline and the Ecological Scarcity 2006, which emphasize different environmental impact aspects. Furthermore, this study was useful in generating a reference case for environmental impacts for the Iasi city water system, and to identify the general improvement alternatives of the current situation and from this point of view this study represents a starting point for a much ample study which will include the development perspectives of the city, those of its water system as well as improvements of LCIA methodologies to better represent the local impacts.

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